EUV mask shadowing effect modeling using a rigorous method

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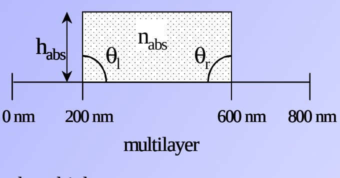
Abstract:

The limited access to experimental studies in EUV lithography gives to the simulation a huge part in the understanding of phenomena. In this context, the modeling of the mask behavior is an important task. The specific structure of the EUV mask, built with a multilayer and an absorber thickness, and illuminated with an off axis ray of light, leads to singular problems observed only for this technique of lithography. One of these problem, addressed on this poster, is the shadowing effect. First a simple 1D approach and then a conical approach using Modal Method by Fourier Expansion are used to consider the effect of the angle of incidence on the CD width and also on the features shift. Isolated and dense lines are considered in this study. Then, different configurations allow to show that it is possible to control the CD shift with using geometric absorber parameters such as height, width or even the slope of each edge considered independently.

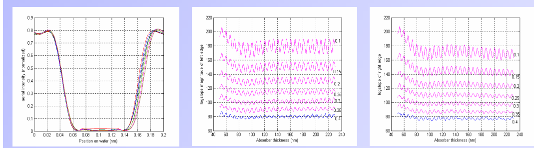
Rigorous modeling method : MMFE (Modal Method by Fourier Expansion)

2D modeling: Influence of parameters on shadowing effect (results on AI):



- Absorber thickness
- Absorber material
- Left and right slope angles

• Absorber thickness:



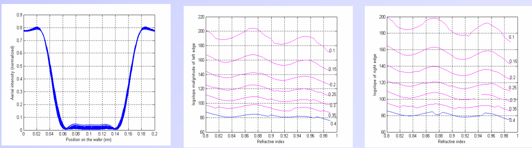
Aerial image | Left edge log slope | Right edge log slope

Absorber thickness variation from 50 to 230nm (Vertical absorber & chrome material)

Small shift on the left edge. The shift on the right edge is more important.

à A thick absorber leads to large feature printed in the resist. The LSR will increase for dense line.

• Absorber material:

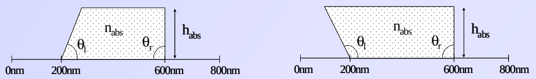


Aerial image | Left edge log slope | Right edge log slope

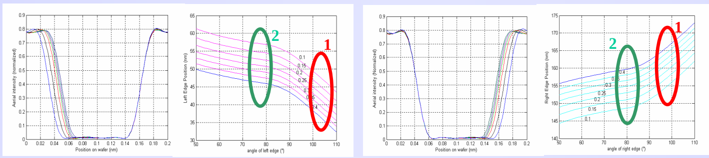
Real part of refractive index variation from 0.8 to 0.99 (Vertical absorber & 80nm thickness)

the change of the refractive index induces a variation of the optical path.
It leads to interference effects similar to a thickness variation.

• Slope Angles:



Absorber shape for angle < 90° | Absorber shape for angle > 90°

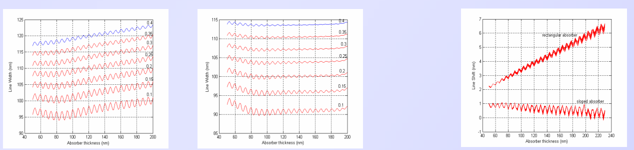


Aerial image | Left edge position | Aerial image | Right edge position

Left & right edge angle variation from 50 to 110° (Chrome material, 80nm thickness)

1- Angle larger than 90°: small angle variation leads to a large shift in the position.

2- Angle lower than 90°: the shift is smaller for a same angle variation.



Line width vs absorber thickness for rectangular shape (left) & for 80° slope edges (right)

Line shift vs absorber thickness. Angles are 94° left & 80° right

Conclusions on 1D modeling: The most influent parameter on the shadowing effect is the thickness of the absorber but the slope of the absorber profile can have a non negligible effect. Simulations show that a modification of the edge angles can reduce the shadowing effect. These adjustments of slope angle are very difficult to achieve in practice. Indeed, different processes used in mask manufacturing such as etching can not be performed with enough control to insure a particular value of parameters such as the absorber slope.

Conical Approach:

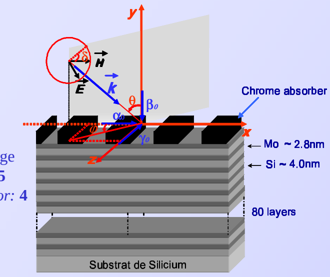
φ: *Conicity angle* δ: *Polarization angle*

Values of constant parameters:

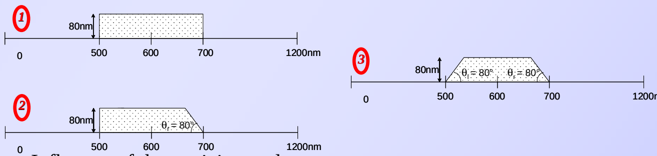
- @ mask:
Width absorber: **200nm**
Period: **1200nm**
Absorber height: **80nm**

Isolated Line

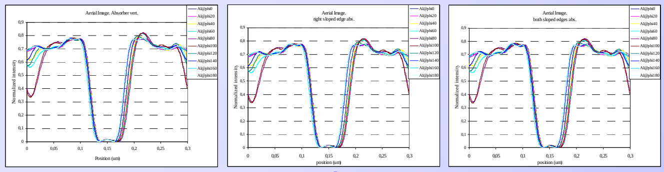
- @ Aerial Image
Threshold: **0.25**
Reduction factor: **4**



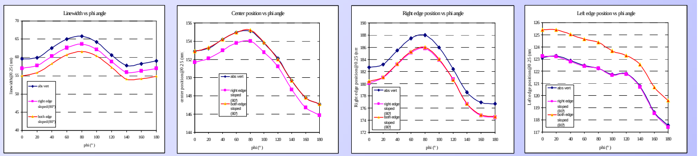
• 3 Absorber shapes



• Influence of the conicity angle φ: $\theta = 5°$, $\delta = 0°$ (TE polarization)

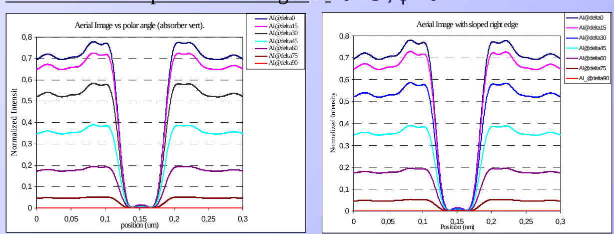


Aerial Images

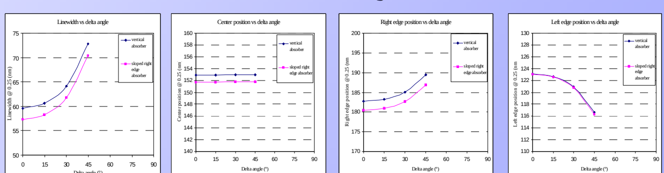


Conclusions on the influence of the conicity angle: For these simulations, the 3 configurations are used. As the variation of the angle is from 0 to 180°, the line is illuminated on both sides. The linewidth increases until φ=80° and then decreases. A sloped absorber reduces the linewidth but keep the same evolution regarding phi angle values. The center position of the line represents the shift. Like the width, the shift increases until φ=80° and then decreases. The shift is null for a particular angle close to 140°. The shape with only the right edge sloped seems to be better to reduce the shift than the full sloped absorber. Nevertheless, a symmetrical shape of absorber seems to be more convenient to address Manhattan lines.

• Influence of the polarization angle δ: $\theta = 5°$, $\varphi = 0°$



Aerial Images



Conclusions on the influence of the polarization angle: The aerial images show that the main effect of the polarization angle is a loss of contrast. δ=0 corresponds to TE polarization and δ=90 to TM polarization. Since φ remains constant and equal to 0, only the variation of the right edge is considered. For a vertical absorber, at threshold 0.25, the loss of intensity leads to an increase of the linewidth, but the shift remains constant (3nm). The slope of the right edge leads to a reduction of the shift below 2nm. The linewidth is also reduced but the variation regarding the angle value remains the same.